JOINT LOADS AND BONE STRAINS ASSOCIATED WITH A RESURFACED FEMORAL HEAD

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INTRODUCTION

In the short-term, the primary mode of failure for hip resurfacing systems is femoral neck fracture near the implant rim (Shimmin, 2005), which may be associated with damage accumulation in this region. Bone damage caused by localized yielding and low-cycle fatigue is associated with high strains (Haddock, 2004; Morgan, 2001). Additionally, likely due to patient selection, motion analysis during normal walking has shown that hip resurfacing patients produce significantly larger adduction/abduction and flexion/extension hip moments than traditional hip replacement patients (Mont, 2007). These larger moments may result in larger joint loads that would increase the likelihood of high strains forming within the femoral neck.

The purposes of this study were: 1) to calculate joint loads associated with hip resurfacing patients and compare these loads to those in patients with traditional hip replacements, 2) to analyze the effect of hip resurfacing on bone strains near the implant rim using the calculated joint loads and nonlinear finite element analysis.

METHODS

The hip loads were calculated using a quasi-static, reduction model (Paul, 1967). Mean and standard deviations for the peak hip abduction and extension moments associated with hip resurfacing and traditional hip replacement patients (Mont, 2007) were used to determine the distribution of hip joint loads (head, abductor, and extensor loads) for each patient group. Since ground reaction forces associated with these moments were not provided, a distribution of the head load direction was based on data from telemetrically implanted patients (Bergmann, 1993 & 2001). Additionally, force equilibrium was constrained by requiring the vertical component of the resultant forces across the hip to equal 1.1BW (Crowninshield, 1979). This approach gave a distribution of joint loads, and ten consecutive draws from these distributions were analyzed for each patient group.

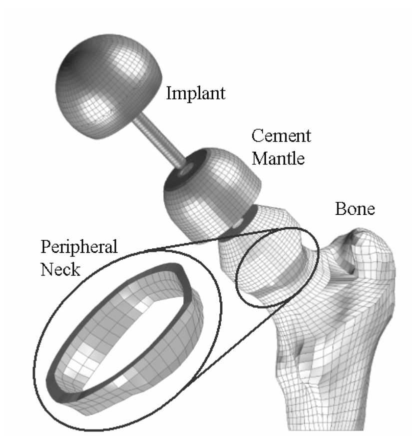

Figure 1: An exploded view of the finite element model of the implanted bone showing the peripheral neck near the implant rim.

Finite element (FE) models of a bone were created from computed tomography (CT) scans for the intact (pre-op) and implanted (immediate post-op) cases. The bone-implant system consisted of the surgically-altered bone, a cement mantle, and an implant (Fig. 1). Bone material properties were assigned element by element using empirical relationships between CT number, apparent density, and elastic modulus (Morgan, 2003). Head and abductor loads were applied to the FE models based upon the ten draws for the hip resurfacing patient group. To analyze the potential for neck fracture, max. and min. principal strains were analyzed in the peripheral bone near the implant rim (Fig. 1).

RESULTS

The head load magnitudes for the hip resurfacing patient group were 3.12$\pm$ 0.32BW compared to 2.66$\pm$0.39BW for the traditional hip replacement group ($P < 0.05$). For the hip resurfacing group, the head load components were -0.88$\pm$0.26BW medial, 0.33$\pm$0.03BW posterior, and -2.96$\pm$0.31BW superior; the abductor load components were 0.71$\pm$0.09BW medial, -0.16$\pm$0.02BW posterior, and 1.52$\pm$0.20BW superior.

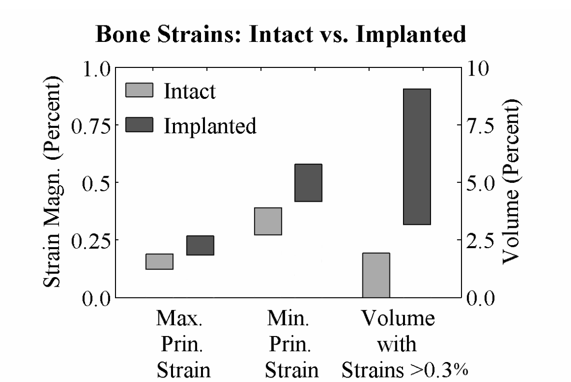

Figure 2: The range of peak principal strains in the peripheral neck and the percent volume of this region with large compressive strains were substantially higher for the implanted compared to the intact bone.

Comparing the intact to the implanted bone, the peak max. and min. principal strains in the peripheral neck increased in magnitude for each load trial, and for all load trials the range of strain magnitudes was substantially higher for the implanted bone compared to the intact bone (Fig. 2). Additionally, the percent volume of the peripheral neck that had min. principal strain magnitudes greater than 0.30% (Burr, 1996) was substantially higher for the implanted compared to the intact bone (Fig. 2).

DISCUSSION

Hip joint loads were found to be significantly higher in the hip resurfacing group compared to the traditional hip replacement group. Additionally, the strains in the peripheral neck, associated with these larger joint loads, were substantially higher in magnitude for the implanted bone compared to the intact bone. This increase in bone strain indicates a possibility of damage accumulation in the femoral neck due to localized yielding and low-cycle fatigue (Haddock, 2004; Morgan, 2001), which may be associated with short-term neck fracture after hip resurfacing.

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